NMSSM Benchmark Proposal

Scenario of Light Dark Matter

Neil Christensen, Tao Han, Zhen Liu and Shufang Su

July 9, 2015

The possibility of providing a suitable light dark matter candidate below 40 GeV is another very attractive feature of the NMSSM. The dark matter candidate needs light Higgs funnel to annihilate efficiently in the early universe, and as a consequence, light Higgs state is predicted. The rich spectrum of light dark matter and light Higgs boson(s) lead to very interesting phenomenology at colliders and dark matter experiments. Such possibility has been discussed recently in Ref. [1] in details, especially the rich Higgs phenomenology in Ref. [2]. In this section, we propose two NMSSM benchmarks to demonstrate such possibility and hope to inspire further studies on this scenario. [1] In this note, we chose two benchmark points, BP LDM1 and BP LDM2 with Singlino-like and Bino-like DM candidate respectively, to exhibit different features of the NMSSM phenomenology.

Parameters and Higgs phenomenology:

The benchmark parameters and Higgs properties are listed in table. 1. Both benchmarks can be viewed as the heavy Higgs decoupling limit of the MSSM plus a singlet, and consequently we only list the light Higgs bosons properties.

For BP LDM1, this benchmark enables two very singlet-like Higgs bosons below 100 GeV. They will contribute to the corresponding DM phenomenology. The SM-like Higgs around 125 GeV is the second mass eigenstate of the CP-even sector. The light Higgs bosons mainly decay into $b\bar{b}$ through their small mixing with the Higgs doublets. The SM-like Higgs has modified couplings and branching fractions to corresponding SM final states. In addition,

[1] The benchmark point is calculated using `NMSSMTools4.6.0` [3, 4], with default options on Higgs mass, $H \longrightarrow V^*V^*$ on and `MicrOmegas` [5] fast computation off.

Parameters	BP LDM1			BP LDM2		
$\tan\beta, \lambda, \kappa$	11.9	0.283	0.0253	12.9	0.0730	0.0645
m_A, A_κ, μ_{eff} (GeV)	2340	-85.4	204	2540	-6.4	244
M_1, M_2, M_3 (GeV)	500	1000	3000	34.6	1000	3000
A_t, A_b, A_τ (GeV)	3790	0	0	3990	0	0
$M_{Q_3}, M_{T_R}, M_{B_3}$ (GeV)	972	3000	2000	1972	3000	3000
$M_{L_3}, M_{\tau_R}, M_{SUSY}$ (GeV)	3000	3000	3000	3000	3000	3000
$m_{H_1}, m_{H_2}, m_{H_3}$ (GeV)	19.1	126	2340	125	430	2480
$m_{A_1}, m_{A_2}, m_{H^\pm}$ (GeV)	73.2	2340	2340	65.7	2480	2480
$\lvert S_{H1h_s}\rvert^2, \lvert S_{H^{\rm SM}h_V}\rvert^2, \lvert P_{A_1a_V}\rvert^2$	0.989	0.989	4×10^{-4}	1×10^{-4}	1.000	8×10^{-6}
Properties	**SM-like H_2**			**SM-like H_1**		
$\kappa_{bb}, \kappa_{\tau\tau}, \kappa_{tt}$	1.02	1.02	0.99	1.00	1.00	1.00
$\kappa_{WW/ZZ}, \kappa_{\gamma\gamma}, \kappa_{gg}$	0.99	0.99	0.99	1.00	1.00	1.00
$\mathrm{Br}_{bb}, \mathrm{Br}_{\tau\tau}, \mathrm{Br}_{gg}$	0.51	0.057	0.047	0.55	0.060	0.051
$\mathrm{Br}_{WW}, \mathrm{Br}_{ZZ}, \mathrm{Br}_{\gamma\gamma}$	0.19	0.024	0.0020	0.19	0.023	0.0021
$\mathrm{Br}_{cc}, \mathrm{Br}_{H_1H_1}, \mathrm{Br}_{\tilde\chi_1^0\tilde\chi_1^0}$	0.023	0.13	0.010	0.025	—	0.10
Properties	**Singlet-like H_1**			**Singlet-like H_2**		
$\kappa_{bb}, \kappa_{\tau\tau}, \kappa_{tt}$	0.12	0.13	-0.11	0.068	0.069	0.010
$\kappa_{WW/ZZ}, \kappa_{\gamma\gamma}, \kappa_{gg}$	-0.10	0.16	0.060	0.011	0.034	0.010
$\mathrm{Br}_{bb}, \mathrm{Br}_{\tau\tau}, \mathrm{Br}_{A_1A_1}$	0.89	0.077	—	0.0007	0.0001	0.85
Properties	**Singlet-like A_1**			**Singlet-like A_1**		
$\kappa_{bb}, \kappa_{\tau\tau}, \kappa_{tt}$	-0.23	-0.23	-0.002	-0.035	-0.036	-0.0002
$\kappa_{\gamma\gamma}, \kappa_{gg}$	0.30	0.057	—	0.066	0.010	—
$\mathrm{Br}_{bb}, \mathrm{Br}_{\tau\tau}, \mathrm{Br}_{\tilde\chi_1^0\tilde\chi_1^0}$	0.90	0.094	—	0.88	0.090	0.027

Table 1: Benchmark parameters and Higgs masses, couplings and decay branching fractions. κs are the relative coupling comparing to the SM Higgs at the same mass.

new decay channels into H_1 pair and $\tilde{\chi}_1^0$ pair are open with up to around 10% branching fractions. Notably, in addition to the light A_1, H_1 can also be very light. Once observed such a bb, $\tau\tau$, $\mu\mu$ resonance state, it might be very interesting to test its CP nature.

For BP LDM2, this bencharmk features one very singlet-like CP-odd Higgs below 100 GeV. The SM-like around 125 GeV is the lightest mass eigenstate of the CP-even sector. The second mass eigenstate of the CP-even sector has its mass 430 GeV, being very singlet like and the direct production rate from glu-glu-fusion, associated production are very suppressed to be below 1% of the SM rate. This singlet-lile H_2 features interesting dominant decays into a pair of A_1, which can lead to interesting $4b/2b2\tau/4\tau$ resonance(s) states to be searched for. Notably, both the SM-like Higgs H_1 and the singlet-light A_1 has several percent branching fractions to the DM candidate, indicating the importance of invisible decay searches for both Higgs bosons.

Dark matter phenomenology:

The LSP singlino-like DM candidate in BP LDM1 and Bino-liket DM candidate in BP LDM2 annihilate resonantly through the lighter CP-odd singlet-like Higgs in both benchmarks. This light CP-odd singlet-like Higgs A_1 serves as a portal connecting the dark matter to SM sector through its mixing with the doublet Higgs. Despite the doublet component of A_1 is very little, as indicated in table. 1, the role of this component is crucial for DM phenomenology. For BP LDM1, A_1 decaying to LSP pair is kinematically forbidden. For BP LDM2, A_1 decay branching fractions to LSP pairs is phase space suppressed to be 3%.

Since the μ_{eff} parameter is not so heavy in the NMSSM, the DM candidate will have some fraction of Higgsinos, which can induce detectable Z boson invisible decay width at future Z factories. The non-singlino component of the LSP affects the DM phenomenology as well. In table. 2, we tabulate properties of the corresponding DM candidate.

The direct detection rates of these DM candidates are mediated mainly by the CP-even Higgs bosons, and are not yet probed fully by current experiments. The low velocity annihilation cross section heavily depends on the kinematics. For BP LDM1, the DM mass is slightly above half the near-resonant mediator A_1 mass, leading to a relatively enhanced annihilation rate at low velocity. This enhanced annihilation rate is in tension with current bounds from astrophysical observations, such as diffusion spectra from dwarf galaxies at Fermi-LAT experiment. For BP LDM2, on the contrary,

DM Properties	BP LDM1			BP LDM2		
$m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_3^0}$ (GeV)	36.7	207	218	32.3	251	256
$m_{\tilde{\chi}_4^0}, m_{\tilde{\chi}_5^0}$ (GeV)	501	1050	—	444	1050	—
$\|N_1\tilde{s}\|^2, \|N_1\tilde{h}_u\|^2, \|N_1\tilde{h}_d\|^2$	0.943	0.001	0.055	0.00002	0.01	0.03
$\|N_1\tilde{B}\|^2, \|N_1\tilde{W}\|^2$	0.0005	0.0004	—	0.968	0.00002	—
$\Omega_{\tilde{\chi}_1^0} h^2$	0.113			0.120		
$\sigma_{\rm p}^{\rm SI}$ (pb)	2.11×10^{-11}			1.99×10^{-10}		
$< \sigma v > (v \to 0)$ $({\rm cm}^3/s)$	1.15×10^{-25}			4.73×10^{-30}		
$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to b\bar{b}$	91%			87%		
$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to \tau^+\tau^-$	9%			8%		

Table 2: The LSP DM candidate properties and related detection cross sections.

the DM mass is slight below half the near-resonant mediator A_1 mass, leading to suppressed rate at low velocity. We also list the main annihilation channels at current epoch in table. 2, and the strong preference into down-type fermions is a direct result of $\tan\beta$ coupling enhancement in the CP-odd sector. Interestingly, with appropriate choice above DM mechanisms, benchmark similar to our choices can serve as a good candidate for the galactic center gamma-ray excess.

References

[1] T. Han, Z. Liu and S. Su, JHEP **1408**, 093 (2014) [arXiv:1406.1181 [hep-ph]].

[2] N. D. Christensen, T. Han, Z. Liu and S. Su, JHEP **1308**, 019 (2013) [arXiv:1303.2113, arXiv:1303.2113 [hep-ph]].

[3] U. Ellwanger, J. F. Gunion and C. Hugonie, JHEP **0502**, 066 (2005) [hep-ph/0406215].

[4] U. Ellwanger and C. Hugonie, Comput. Phys. Commun. **175**, 290 (2006) [hep-ph/0508022].

[5] G. Belanger, F. Boudjema, C. Hugonie, A. Pukhov and A. Semenov, JCAP **0509**, 001 (2005) [hep-ph/0505142].